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EVALUATION OF
HUMAN ENCODING PERFORMANCE
WITH VARIED DISPLAY MEDIA

Michael Joseph O'Keefe

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THESIS

EVALUATION OF
HUMAN ENCODING PERFORMANCE
WITH VARIED DISPLAY MEDIA

by

Michael Joseph O'Keefe

June 1976

Advisors: L. E. Waldeisen
D. E. Neil

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20. (continued)

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Evaluation of Human Encoding Performance With Varied Display Media

by

Michael Joseph O'Keefe
Lieutenant, United States Navy
B.A., San Diego State College, 1969

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

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Without the constant help of thesis advisors, the writer could have gone far astray in planning the many details of method and procedure necessary for the successful performance of a scientific experiment.

I. INTRODUCTION

A. BACKGROUND

Human factors engineering has been defined as "that branch of modern technology which deals with ways of designing machines, operations, and work environments so that they match human capacities and limitations." [Chapanis, 1959]

With the advent of complex systems that rely more upon the operator's sensory, perceptual, judgmental, and decision-making ability vice his muscular power, the role of the human factors engineer in designing these systems became more necessary. Unfortunately there was a paucity of information regarding these human functions for the human factors engineer to draw upon; therefore, the first step was in research and data collection. The term man-machine system has been adopted to describe systems in which man and machine interact. Chapanis [1965] has defined such a system as "an equipment system in which at least one of the components is a human being who interacts with or intervenes in the operation of the machine components of the system from time to time." In order to optimally design man-machine systems, understanding of the limitations of the human operator is essential. As suggested by Chapanis [1965], in the design of a complex system, almost everything known about man is important: body dimensions; physiological reactions to environmental stresses such as

accelerative forces and extreme variations in temperature and atmospheric pressure; sensory capacities in relation to instrument and display indications; the ability to make timely decisions; the ability to make correct control movements; learning or the modification of behavior through training; eating, drinking; and the psychological consequences of fatigue, emotion, and isolation.

A man-machine system is usually designed with some specific objectives in mind as well as the specification of performance requirements. With the objectives and peformance requirements decided upon, certain functions that need to be performed are determined by the designer to meet the stated objectives. As reported by McCormick [1970], certain functions are predetermined to be allocated to the human component and others to some physical (machine) component due to superiority of one over the other or economic considerations. However, a range of these functions could be within the capability of man or machine. In some instances limitations were imposed and mistakes made due to the lack of adequate data on which to base function allocations. McCormick [1970] supports this view by adding that "the gaps in, and limitations of, data on human performance in certain areas make it impossible, or at least treacherous, to set forth definitive statements about human capabilities in those areas."

A major problem involved in the design of man-machine systems concerns the methodology necessary to measure complex system

performance from the standpoint of human operator efficiency. This problem concerns designing a system and its machine components so that they best complement the capabilities and limitations of the human operator who must work in the system. Before the complexities of human performance can be understood, there must be a unified framework for studying it. There exist limits to man's ability to sense, attend to, process, store, and transmit information; and the more we discover about these limits the better man-machine systems will be designed. Fitts and Posner [1967] have suggested the need to seek for the simpler components within complex skills in an effort directed toward gaining an understanding of human performance that allows discussion of complicated and practical tasks. Since human performance is considered in terms of various sensory, mental, and motor activities it is difficult if not impossible to measure human performance in strictly human activity terms for specific work situations, since such performance is usually inextricably intertwined with the performance characteristics of the physical equipment being used. It is therefore necessary for the scientist to control his conditions in order to be sure of what he is observing. Ideal (laboratory) conditions generally involve few variables and allow for description in simple terms. Having identified the performance to be expected under ideal conditions, it is frequently possible to extend the model to include the additional variables associated with the operational system. The ideal

situation, in other words, constitutes a convenient base from which to explore the complex performance of the operator in the operational environment. In certain cases, values of ideal conditions may actually approximate very closely the characteristics of the operator in the real world. The problem then becomes one of changing the ideal model in some variable so that it is slightly less than ideal. This method of attack has been found useful in generating hypotheses for further study. Thus, whereas it is not expected that the man-machine system will behave identically to the laboratory design, the emphasis in early studies is on similarities. If the differences are small, one may rule out entire classes of alternative models, and regard the model in question as a useful tool in further studies. Proceeding on this assumption, one may then in later studies emphasize the differences; the form and extent of the differences, suggesting how the ideal model may be modified in the direction of reality. It must be recognized, however, that there are problems with conducting research in this manner. Chapanis [1967] urged extreme caution, indicating that although results of such studies might suggest ideas and hunches that could be tried out in practical situations, one should be careful in generalizing or extrapolating the results. However, as McCormick [1970] points out, there may not be relevant data available from real-world studies. Alpern, Lawrence, and Wolsk [1967] support this need, as well as the caution.

"Only through a process of step-by-step reduction is it possible for researchers to get deeper and deeper, from the psychological down to the molecular relationships of sensory mechanisms. In doing this, it is important for them and for the student to realize that there is no 'vision' or 'hearing' at the molecular level and that the path back up is a many-branching path. Two different organisms, even though starting with similar eyes, do not see the same things."

B. THE PROBLEM

Previously the identification of display and control elements for machines had been achieved predominantly by written words and abbreviations but due to the complexity of systems and amount of information presented to the operator designers have resorted to highly structural and simplified symbols for machine displays. As discussed by Hitt [1961] there have been a number of studies conducted to compare code levels within a single code category and a few studies to compare the effectiveness of one code category with the effectiveness of a second code category, e. g., Erikson [1952] investigated speed in locating targets on a visual display when the various classes of objects on the display differed from one another on only one of the four dimensions of form, hue, size, and brightness. He concluded that location time for differences was significantly shorter than for form differences. The present purpose was not to decide which is best but

to establish a data base for the encoding time. The data gathered were determined under specific lab conditions and it is realized that to such data must be added case-specific variables of luminous environment, unknown location, movement, variable duration of movement, environmental stress, operator motivation, as well as many others. It was believed important to undertake a means of assessing the extent of the involvement of the man in these complex systems. If under ideal conditions it was found that an operator took a certain amount of time to encode some information, then it would be useless to design a machine that would require an operator to encode more information in the same amount of time since the ultimate conditions for use of the machine would be less than ideal.

The impetus for the present study was the need to establish a performance measurement data base in support of hardware simulation required by the Human Engineering Division (CSD), Naval Air Development Center (NADC). More specifically, NADC requested the time for a complex systems operator to encode information commonly presented by systems hardware displays. The categories of information included: symbology, size of font, numbers, letters, colors, words, and orientation of pointers. Therefore, it was necessary to determine what was necessary for encoding to occur and how to measure this process.

1. Introduction

Posner has reported that all human information processing requires keeping track of incoming stimuli and bringing such input into contact with already stored material [Haber 1969]. Furthermore, Haber [1969] has suggested that sensation, perception, memory, and thought must be considered on a continuum of cognitive activity; therefore, it is not possible to understand perception, especially recognition, identification, and perceptual memory, without understanding the whole range of cognitive theory. The present author felt it necessary to discuss certain areas of cognitive theory under separate headings before discussing encoding since, for encoding to occur, there must be a sensory reception of a stimulus as well as a perceptual process that involves the interaction of sensory processes and the cortex (memory).

2. Perception and Sensation

As reported by Alpern et al [1967] and supported by Welford [1970], far more data are transmitted by our sense organs to the brain than we in fact perceive. Also regarded as obvious by Welford [1970], although frequently overlooked, is the position that the data that we do perceive are grouped and ordered. Alpern et al [1967] have suggested that what is involved is an active filtering and selection in the brain of sensory input. People attend only to a small fraction of the available stimulus information which is needed for ongoing

behavior and are unaware of the remaining sensory stimulations. Those who have driven a car and missed a turn while daydreaming about something else have experienced this phenomena. The net result of both the selection and the integration involved is an economy in handling data. Selection and integration commonly go hand in hand: the ordering of data involved in perceiving an object as such, implies a kind of selection in that attention is paid to some data, while the remaining information is relegated to a background which is largely ignored and commonly cannot be reported in much detail.

Due to the interdependence of sensation and perception there are different viewpoints as to what is sensed and perceived. Berkeley [1910] in 1709 provided the thesis that visual sensations themselves do not provide much knowledge about the world but that they do provide a basis for arriving at correct interpretations. Berkeley asserted a distinction between sensation and perception since what was perceived was sometimes different from the physical stimulus. Rock [1975] concluded that perception and sensation are not the same but interdependent relying upon such things as motivation, past experience, and expectations. The Gestalt school of thought criticized the distinction between sensation and interpretation (or perception). That is, Gestalt theorists essentially protest all forms of analytic reductionism that attempts to understand complex human psychological processes by establishing their irreducible basic elements.

Haber [1970] defined "perceptual" as "all those processes concerned with the translation of stimulus energy falling on a receptor surface (limited to visual for this discussion) into the reports of experience, responses to that stimulation, and memory persisting beyond the termination of that stimulation." Haber [1970] assumed that a perceptual response is not an immediate consequence of stimulation, but one which had gone through a number of stages or processes, each of which took time to organize or traverse. He has suggested that this processing is limited by the capacities of the information-handling channels, the information content of the stimulus, and the prior experiences and condition of the perceiver. In addition, Haber has suggested that perceptual processes cannot be studied or analyzed independent of memorial ones, since recoding and preservation of information occur at all stages of information processing.

Haber was supported by Norman [1969] whose aim was to follow what happens to the information as it entered the human and was processed by the nervous system. Ignoring the interconnections among the levels of processing, a simplified procedure could be stated as follows: the sense organs provide the picture of the visual world, therefore, the problem is to interpret the sensory information and extract its psychological content. To do this it is necessary to process the incoming signals and interpret them on the basis of past experience. Memory is considered to play an active role in this process for it

provides the necessary information about the past used in interpreting the present. It is also considered necessary to have a temporary storage facility to maintain the incoming information while it is being interpreted.

3. Short Term Memory

a. Definition

As stated previously, all human information processing requires keeping track of incoming stimuli and bringing such input into contact with already stored material. In general, short term memory (STM) systems refer to the storage capacity available to perform the comparison of incoming stimuli with already stored material within ongoing serial activity. Posner [1967] stated that the term STM has been used to refer to three distinct features of such a memory system. One sense in which STM has been used is a relatively direct representation of the stimulus, as opposed to memory systems which involve symbolic recoding, such as storing the name or description of the stimulus. This direct representation of information without verbal encoding is required to explain the learning and retention of many skills, such as tracking, which involve complex patterns of input and sequences of movement. It is commonly agreed that such representational storage exists, at least in the form of visual after-images, for very short periods of time [Melton, 1963]. It has been typical to identify representational storage as a very early stage in information

processing which decays in the order of a second or two unless coded into verbal form [Sperling, 1963]. Fitts and Posner [1967] reported this first type of definition of STM as being a sensory one in which the stimuli may not reach a conscious level in the individual. They have described this level as follows:

> "At the neuro-physiological level, electrical phenomena associated with sensory stimulation of short duration, such as a click or a 1-millisecond flash, persist for at least several hundred milliseconds after the event."

The second sense in which STM has been used is the concept of an "operational memory" [Hunter, 1964]. This refers to information stored in long term memory which has been activated in the process of solving a particular problem. An example of this type would be to add together the digits of your telephone number. It is necessary to keep available the stored digits of the phone number during the course of producing their sum.

The third sense, and most common definition of STM, relates to the interval between presentation and recall. It was defined by Fitts and Posner [1967] as "a system which loses information rapidly in the absence of sustained attention." Sperling [1963] and Mackworth [1964] have presented evidence that this attention involves the audio-speech system for visual stimuli. That is, to retain information it is necessary for the person to say to himself aurally what

the information is whether it be vocally or subvocally. This last definition is the most applicable to the present study.

b. Theory of Short Term Memory

The view proposed by Broadbent [1971] and held by a number of researchers today is the existence of a buffer store, a short term memory, and a long term memory store (three stage system) although some refer only to short and long term stores. Following Brown [1958], Broadbent [1971] proposed that memory for more than a few seconds (i. e., STM) was facilitated by rehearsal. During rehearsal items to be remembered were continuously recirculated between a buffer storage, just after reception by the sense organs, and a limited capacity storage system. If intervening items were presented during rehearsal, a number of the original items would be lost from memory. Otherwise the original items would gradually be transferred to a longer term storage system. Miller [1958] showed that information content was not the critical element in STM due to processes called "chunking" (to be defined later), and "coding" of information. Broadbent [1971] referred to coding as a "further process": "If an item has been presented, it will enter this early stage of buffer storage, but unless some further process takes place within the first second or so, the item will be lost."

Before moving from the discussion of STM theory into a discussion on encoding some of the issues, or subtheories, contained within the study of STM will be addressed.

(1) Rehearsal. The importance of rehearsal in STM has already been stated. Virtually all of the theories of STM acknowledge the necessity for rehearsal in maintaining a short term store. Peterson and Peterson [1959], Murdock [1961], and Sanders [1961] all reported the maintenance of STM given rehearsal. Welford [1968] states:

> "The reasons for these rehearsal effects are not, however, entirely clear. To some extent rehearsal may serve to keep the memory traces from decaying, but this cannot account for the increased resistance to interference from intervening activity. Brown [1958] reported that many of his subjects made remarks which implied that they were somehow recoding the material during rehearsal or were applying mnemonic devices such as forming associations -- he mentions one subject who associated the letters ND with the words 'National Debt'."

Rehearsal can occur vocally or subvocally. The subject in an experiment can be observed or heard vocally repeating stimuli to be remembered. The subject's lips may also be seen moving in subvocal rehearsal. The subvocal rehearsal is a type of inner-communication rather than a conscious rehearsal. Haber reported this range of rehearsal as follows:

> "In most analyses of STM, rehearsal is equated with repeating things to oneself. From an information processing viewpoint, it may be useful to consider rehearsal as demanding a portion of the limited information processing capacity of the subject [Broadbent, 1958]. Thus in verbal tasks it may involve covert speech while in other situations [Posner and Knock, 1966b] something more akin to concentration may be appropriate. Such a view of rehearsal reduces the necessity of relying upon introspective accounts of instructions to determine if a subject is rehearsing. Moreover, it allows the comparison of memory systems, both human and animal, which are clearly verbal with those which are not."

Whether rehearsal is vocal or subvocal, both play an important part in STM.

(2) Chunking. Norman [1969] hypothesized that "we can improve our apparent memory span by recoding or 'chunking' information"; chunking as defined by Miller [1958]. Miller [1958] has concluded that immediate memory appears to be limited by the number of items, regardless of the information content and, because of this, the memory span could be increased by efficient grouping of old items

into new items. For example, it would be difficult to remember 20 random letters if presented for 5 seconds, but not if they were chunked into 3 familiar words. Vernon [1952] postulated that we chunk (in his terms "group") unconsciously in an attempt to impart meaning. Vernon [1952] has suggested the following:

> "With any perception process there is a spontaneous tendency on the part of the observer to segregate the incoming sensory patterns into groups. The observer segregates the visual field into separate comprehensible parts."

c. Encoding

Haber [1969] suggested that the first stage in the memory process involves translating external stimulation into some sort of internal code. Sperling [1963] theorized that both visually and aurally presented information is read into an auditory information storage system at a very rapid rate. This basic notion has received support from studies of acoustic confusion errors in recall of visual material [Conrad, 1964], correlations between overt reading rates and memory span [Mackworth, 1964], and correlations between recall errors and the description lengths for nonsense patterns [Glanzer and Clark, 1963]. Norman, quoting from Miller's paper to which previous reference was made, discussed the process of encoding. (Note: encoding takes place before the items entry into a conscious level.) From Norman:

> "The differences between our ability to retain things in immediate memory result from differences in the types of information processing involved. When we try to make an absolute judgment we are trying to encode information. That is, we are trying to categorize the stimulus input according to previously learned classifications."

Norman stated that the encoded information is the material that is stored. Norman hypothesized that "we can improve our apparent memory span by recoding or 'chunking' information"; chunking used as defined by Miller. Broadbent argued that encoding (in his terms "classification") occurs during perception of the item. Perception occurs after the item's initial pass through the buffer store and before the item is recirculated to the buffer store.

II. METHOD

A. DESIGN

An order-free Latin Square design was used for the present experiment in which all 40 slides were presented to the 20 subjects and no two subjects were presented the slides in the same order. This design is depicted in Figure 1.

B. SUBJECTS

The subjects for the experiment were 20 male students attending the Safety School Program at the Naval Postgraduate School, Monterey, California. All the subjects were military aviators with normal color vision and visual acuity at or corrected to 20/20. The subject's mean flight time was 1743 hours with a low of 350 hours and a high of 3360 hours. Subjects ranged in age from 24 to 35 with a mean age of 29. Subjects were volunteers and performed without monetary compensation.

C. APPARATUS AND STIMULI

1. General Layout

Subjects were seated at a desk in an Industrial Acoustic Company, Inc. controlled acoustical environment booth in which their head was maintained in a steady position 28 inches from the 10 inch square rear projection screen based upon specific human-engineering recommendations (Human Engineering Guide, 1972). This layout is shown in Figure 2.

Subjects

Order

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
3	6	9	12	15	18	21	24	27	30	33	36	39	1	4	7	10	13	16	19
4	8	12	16	20	24	28	32	36	40	3	7	11	15	19	23	27	31	35	39
5	10	15	20	25	30	35	40	4	9	14	19	24	29	34	39	3	0	13	18
6	12	18	24	30	36	1	7	13	19	25	31	37	2	8	14	20	26	32	38
7	14	21	28	35	1	8	15	22	29	36	2	9	16	23	30	37	3	10	17
8	16	24	32	40	7	15	23	31	39	6	14	22	30	38	5	13	21	29	37
9	18	27	36	4	13	22	31	40	8	17	26	35	3	12	21	30	39	7	16
10	20	30	40	9	19	29	39	8	18	28	38	7	17	27	37	6	16	26	36
11	22	33	3	14	25	36	6	17	28	39	9	20	31	1	12	23	34	4	15
12	24	36	7	19	31	2	14	26	38	9	21	33	4	16	28	40	11	23	35
13	26	39	11	24	37	9	22	35	7	20	33	5	18	31	3	16	29	1	14
14	28	1	15	29	2	16	30	3	17	31	4	18	32	5	19	33	6	20	34
15	30	4	19	34	8	23	38	12	27	1	16	31	5	20	35	9	24	39	13
16	32	7	23	39	14	30	5	21	37	12	28	3	19	35	10	26	1	17	33
17	34	10	27	3	20	37	13	30	6	23	40	16	33	9	26	2	19	36	12
18	36	13	31	8	26	3	21	39	16	34	11	29	6	24	1	19	37	14	32
19	38	16	35	13	32	10	29	7	26	4	23	1	20	39	17	36	14	33	11
20	40	19	39	18	38	17	37	16	36	15	35	14	34	13	33	12	32	11	31
21	1	22	2	23	3	24	4	25	5	26	6	27	7	28	8	29	9	30	10
22	3	25	6	28	9	31	12	34	15	37	18	40	21	2	24	5	27	8	30
23	5	28	10	33	15	38	20	2	25	7	30	12	35	17	40	22	4	27	9
24	7	31	14	38	21	4	28	11	35	18	1	25	8	32	15	39	22	5	29
25	9	34	18	2	27	11	36	20	4	29	13	38	22	6	31	15	40	24	8
26	11	37	22	7	33	18	3	29	14	40	25	10	36	21	6	32	17	2	28
27	13	40	26	12	39	25	11	38	24	10	37	23	9	36	22	8	35	21	7
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29	17	5	34	22	10	39	27	15	3	32	20	8	37	25	13	1	30	18	6
30	19	8	38	27	16	5	35	24	13	2	32	21	10	40	29	18	7	37	26
31	21	11	1	32	22	12	2	33	23	13	3	34	24	14	4	35	25	15	5
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35	29	23	17	11	5	40	34	28	22	16	10	4	39	33	27	21	15	9	3
36	31	26	21	16	11	6	1	37	32	27	22	17	12	7	2	38	33	29	23
37	33	29	25	21	17	13	9	5	1	38	34	30	26	22	18	14	10	6	2
38	35	32	29	26	23	20	17	14	11	8	5	2	40	37	34	31	28	25	22
39	37	35	33	31	29	27	25	23	21	19	17	15	13	11	9	7	5	3	1
40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21

Figure 1. Order-free Latin Square Design

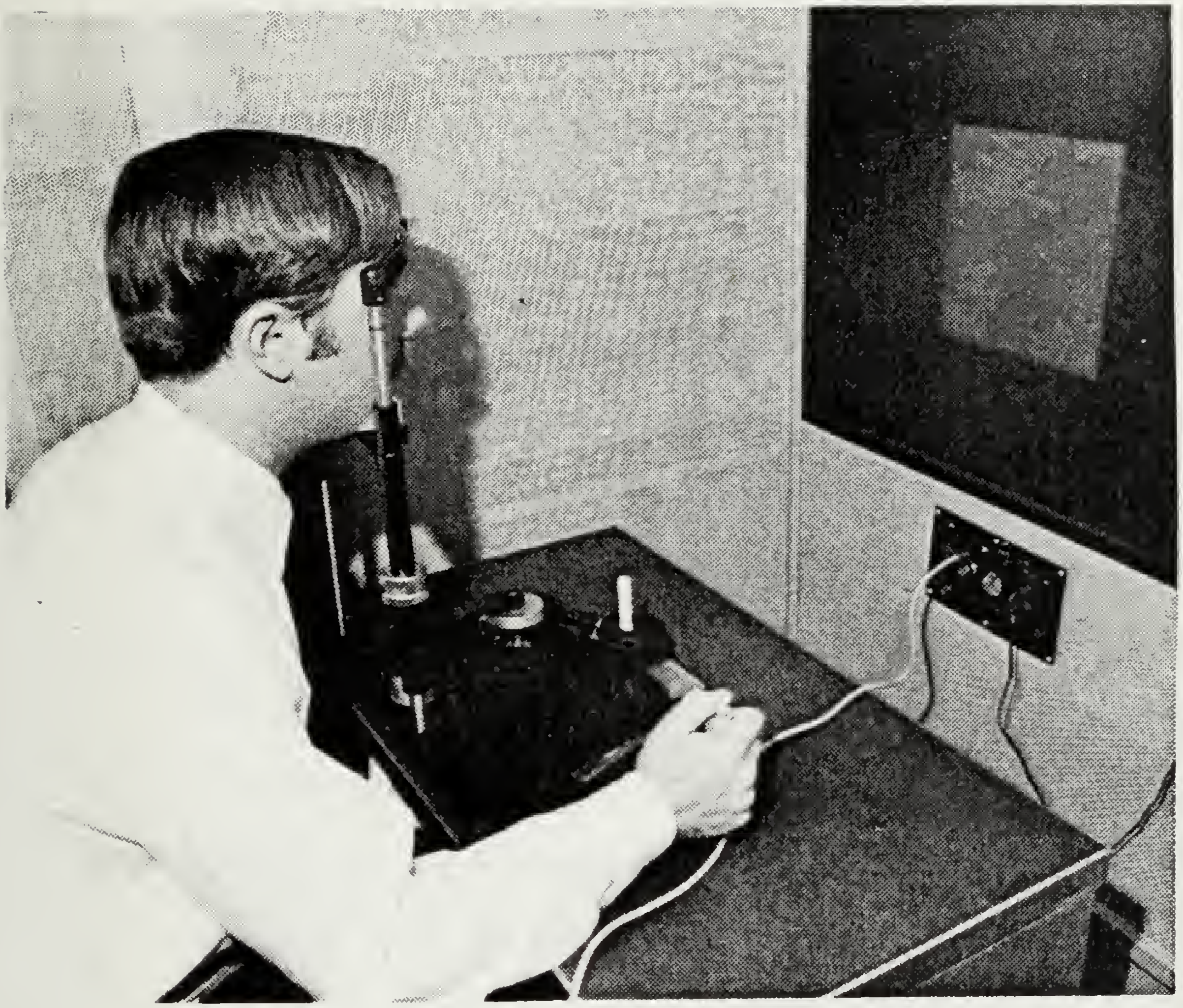


Figure 2. Booth Layout

A one-inch square green indicator light was located above the screen which, when not illuminated, meant that subjects were free to push the toggle switch which caused the next slide to appear on the screen. The slide was projected onto the screen from a rear-mounted Lafayette Instrument Co. tachistoscope mounted to a Kodac Carousel Projector controlled by a Lafayette Instrument Co. 12910 random access machine. The slide would appear on the screen until the subject released the toggle switch at which time the green indicator light would appear for 3.5 seconds to insure adequate time for the random access machine to cycle the slidetray to the next slide. This equipment is pictured in Figure 3.

Also wired to the toggle switch was a digital lab 8/e computer manufactured by Digital Equipment Corporation which timed the depression of the toggle switch within three milliseconds and printed out the results on a teletype as shown in Figure 4.

2. Slides

There were two basic formats for the slides, the first consisting of a single X covering the whole slide. This was the reaction time slide of which there were two and is depicted in Figure 5.

The second format consisted of 16 elements all equally spaced when presented on the ten inch square screen. The size of the screen was computed using a 28 inch viewing distance and visual angle from

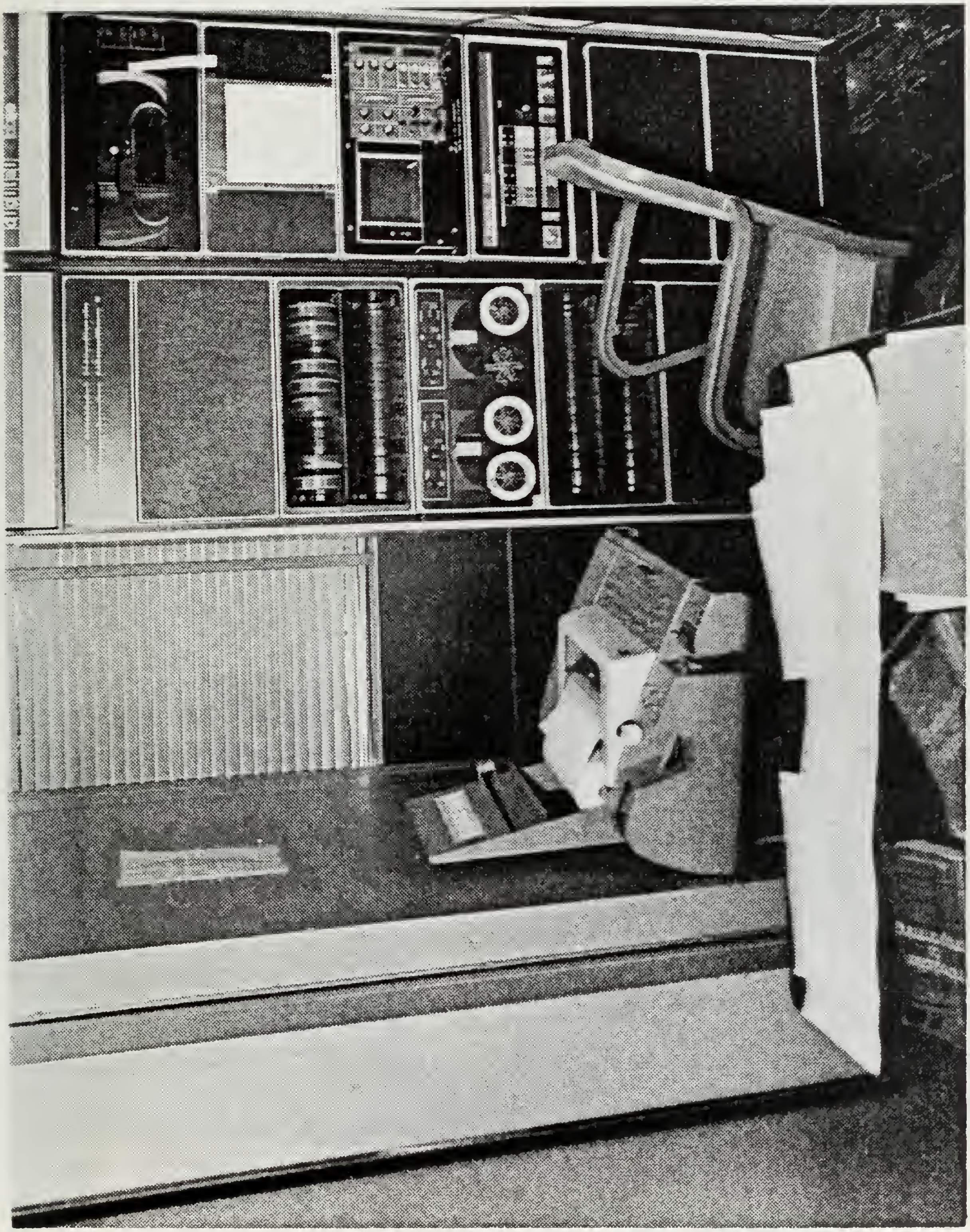


Figure 3. Outside Equipment Layout

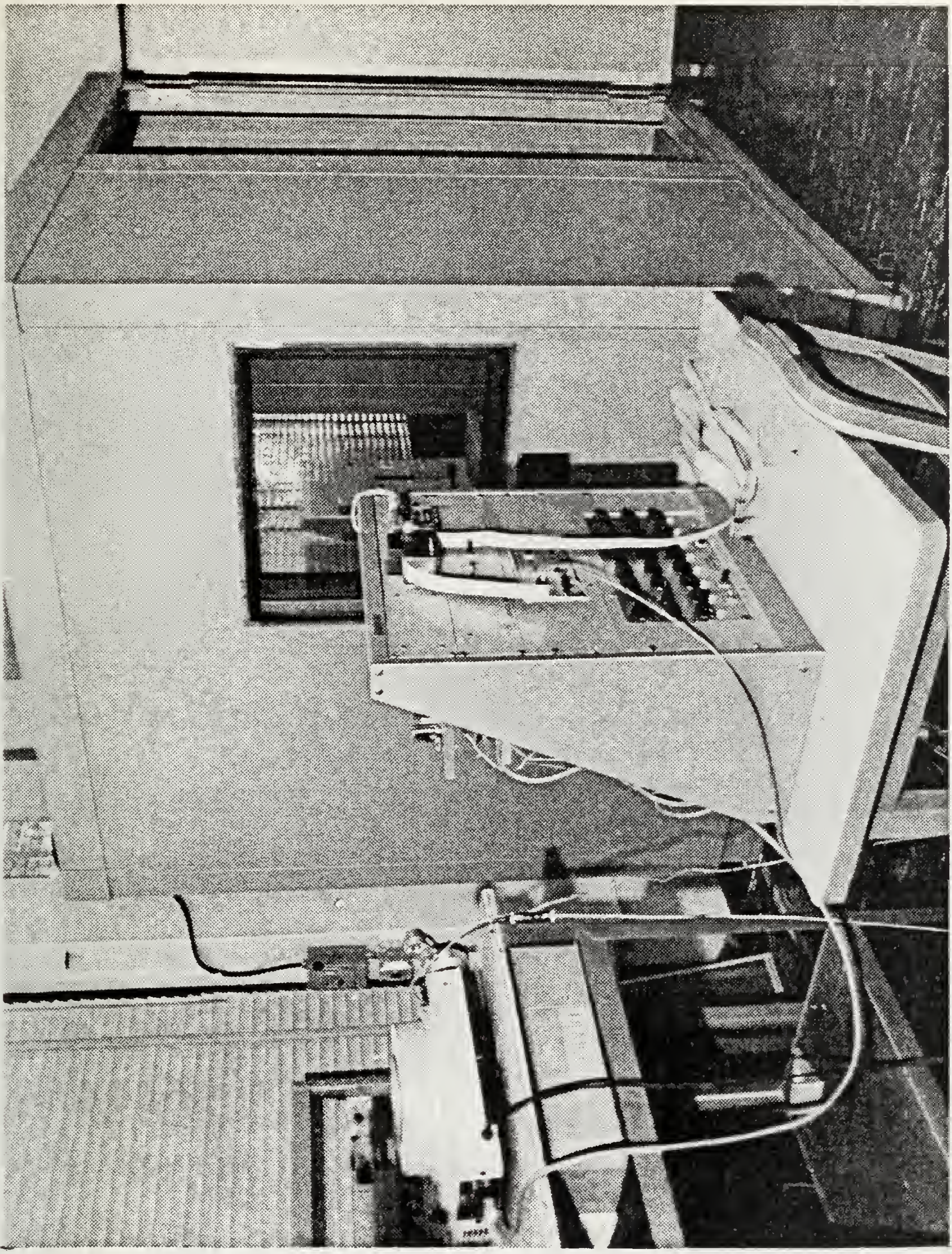


Figure 4. Digital Lab 8/e Computer and Terminal

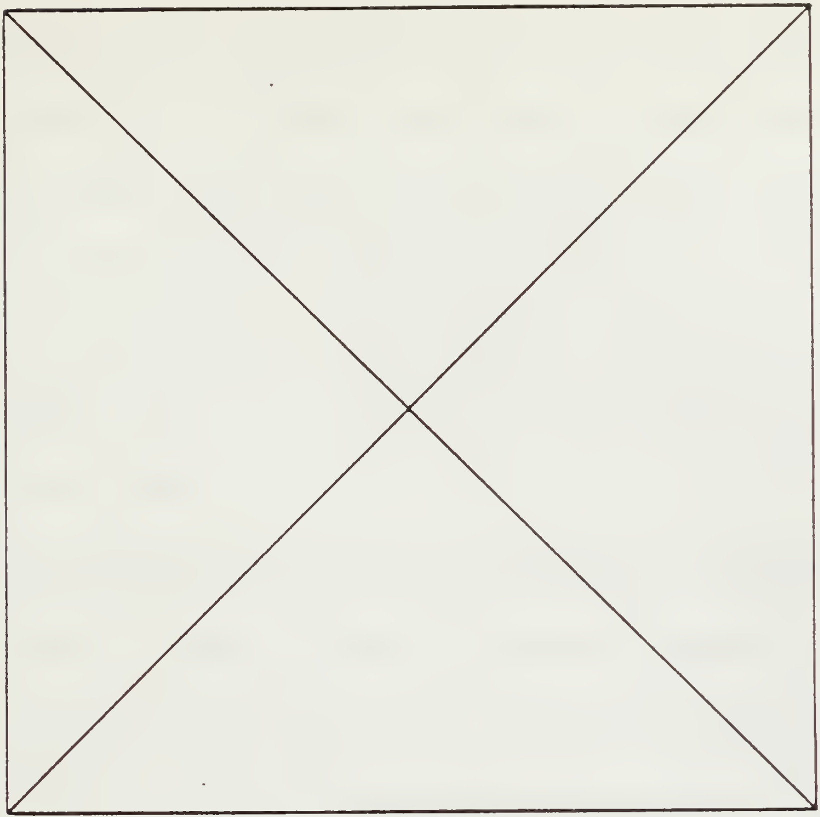


Figure 5. Reaction Time Slide

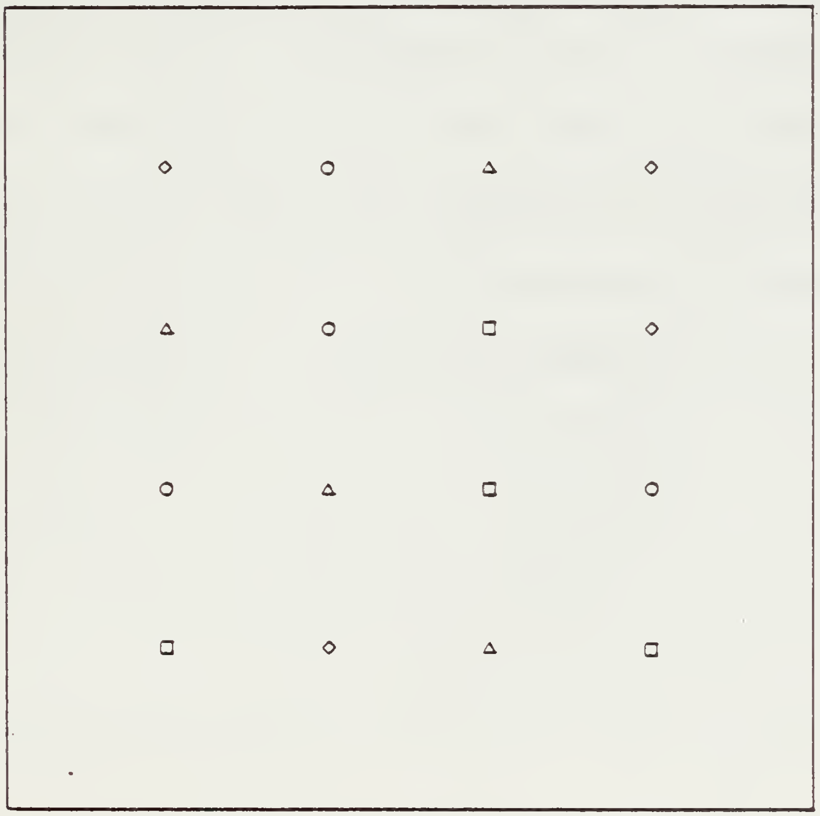
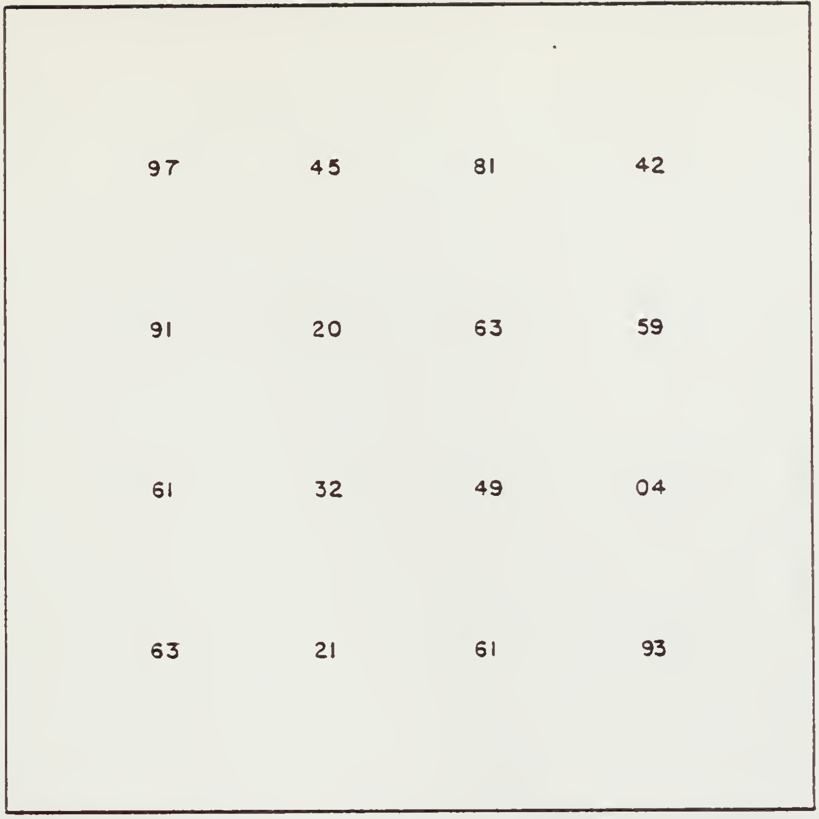


Figure 6. Geometric Symbols Slide

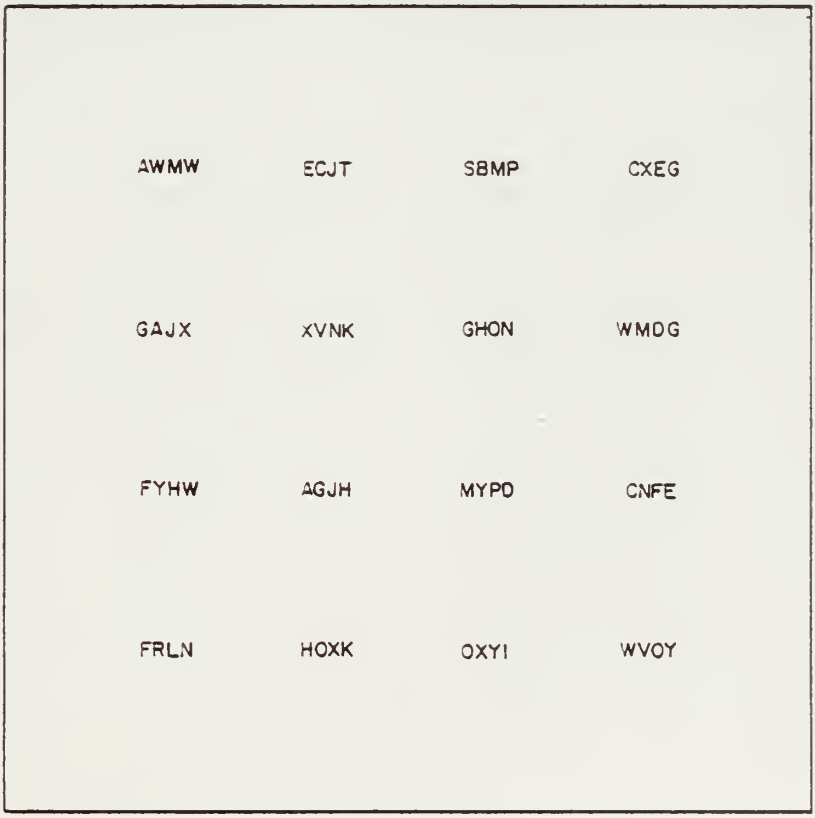
MIL-STD-1472 (1970). The differences among these slides were their elements which were designed using available human engineering design principles.(Human Engineering Guide, 1972). The selection of colors, configuration, and geometric shapes, for instance, was based upon the results of previous research (McCormick, 1970); the size of certain elements being .13, .15, 1.8 was based on recommendations of MIL-STD-1472 (1970).

The elements of format two consisted of: geometric symbols (circle, triangle, square, diamond), numbers (one, two, or four per element), random letters (one, two, or four per element), pointers (up, down, right, or left), common words (two, three, or four letters per element), square boxes (eye movement slide), and colors (red, yellow, green, or blue). An example of each type is shown in Figures 6 through 11 respectively except colors. The colors used were Munsell colors G#139, R#11, Y#82, and B#178 on W#263 background. The size of each color element was the same size as the eye movement boxes, one inch square. The remaining elements had three sizes: .13, .15, and .18 inch. The total number of slides by type are summarized as follows: reaction time (2), eye movement (2), geometric symbols (3), numbers (9), letters (9), pointers (3), words (9), and colors (3). The order of all the elements and the parts of the elements were randomly selected with no consequtive repeats. [Haber, 1969]



97	45	81	42
91	20	63	59
61	32	49	04
63	21	61	93

Figure 7. Numbers Slide



AWMW	ECJT	SBMP	CXEG
GAJX	XVNK	GHON	WMDG
FYHW	AGJH	MYPD	CNFE
FRLN	HOXK	OXYI	WVOY

Figure 8. Random Letters Slide

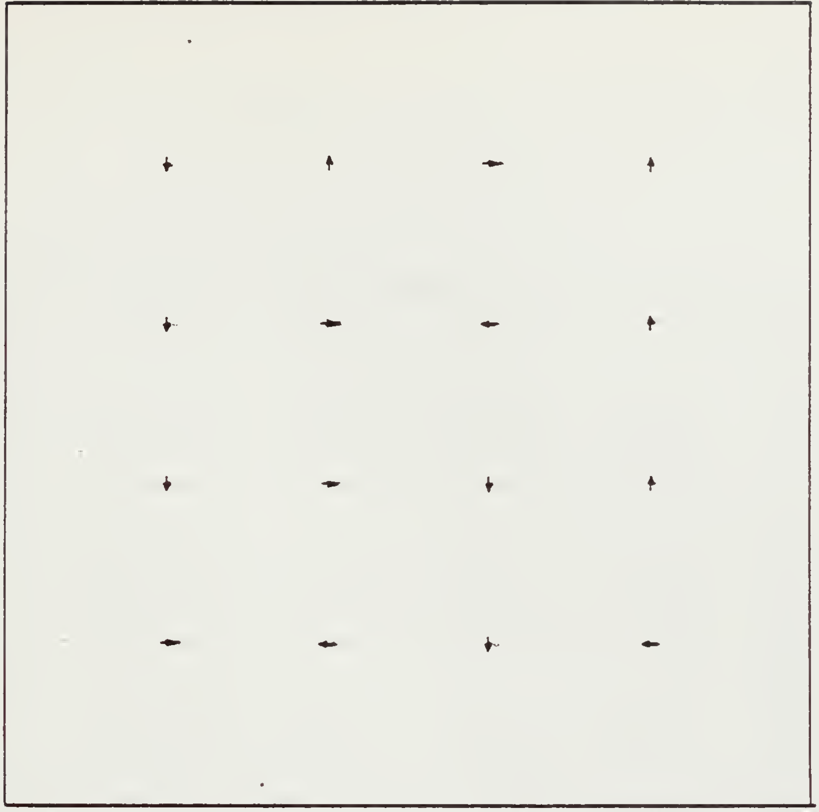
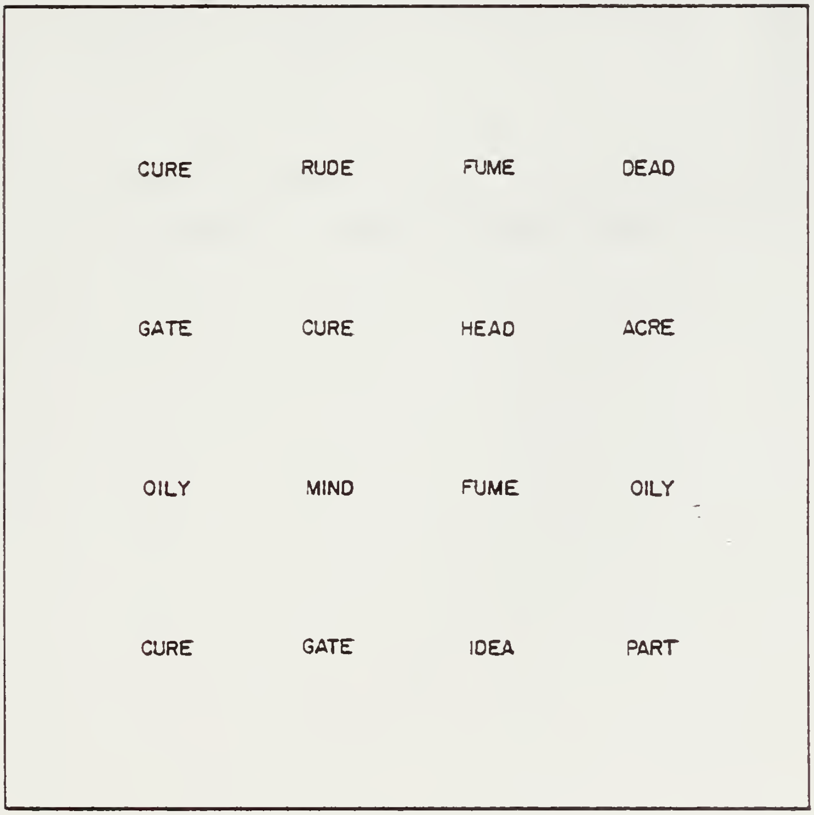


Figure 9. Pointers Slide



CURE	RUDE	FUME	DEAD
GATE	CURE	HEAD	ACRE
OILY	MIND	FUME	OILY
CURE	GATE	IDEA	PART

Figure 10. Common Words Slide

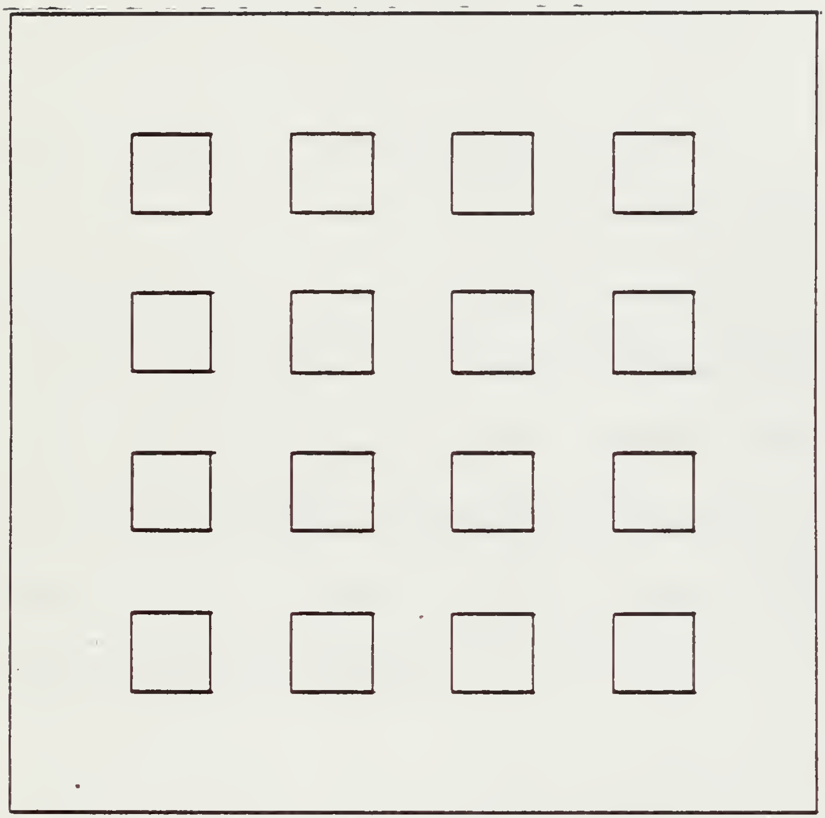


Figure 11. Square Boxes Slide

D. PROCEDURE

The experiment was conducted in the Man-Machine Systems Design Laboratory at the Naval Postgraduate School. Subjects were required to view 40 slides in a self-paced mode after being shown the equipment in the booth, given taped instructions (Appendix A), and a practice session of each of the different types of slides.

Upon completion of the experiment subjects were given a questionnaire (Appendix B) to fill out at which time they were questioned regarding subvocalization. Then they were thanked for their time and instructed not to discuss the task with other subjects. They were also encouraged to ask any questions concerning the purpose of the experiment, its design, or the equipment used for the experiment and these questions were answered at this time.

III. RESULTS

The variable and its associated number is given in Table I with the results summarized in Table II. The data is in three groups whose difference was the ASRT time and will be explained in the Discussion Section. The ASRT times for the three groups was as follows: Control Group, 3.24 seconds; N-1-.18 Group, 4.714 seconds; ASRT Group, 6.003 seconds. ART is the average reaction time from the two slides from all 20 subjects which was .745499 second. ASRT is the eyescan time with reaction time included; therefore, M-ASRT + ART is the mean minus average eye scan time, M-ART is the mean minus average reaction time, and M-ASRT is the mean minus both reaction and eye scan time. The mean and M-ART are only tabulated for the Control Group because the results are the same for the N-1-.18 and ASRT Groups. The standard deviation is the same for all groups. The most relevant data, M-ASRT of the Control Group is plotted in Figure 12.

Variable Number	Variable
1	N-1-. 18
2	L-1-. 18
3	N-1-. 15
4	N-1-. 13
5	L-1-. 15
6	L-1-. 13
7	W-4-. 18
8	W-3-. 15
9	W-3-. 13
10	W-4-. 15
11	W-3-. 18
12	W-2-. 15
13	W-2-. 18
14	W-4-. 13
15	W-2-. 13
16	N-2-. 18
17	COLORS
18	N-2-. 15
19	N-2-. 13
20	POINTER-. 18
21	L-2-. 15
22	L-2-. 18
23	POINTER-. 15
24	POINTER-. 13
25	SYMBOL-. 15
26	SYMBOL-. 18
27	L-2-. 13
28	SYMBOL-. 13
29	L-4-. 18
30	L-4-. 15
31	L-4-. 13
32	N-4-. 18
33	N-4-. 15
34	N-4-. 13

Variable Legend

Letter

N-number
L-letter
W-word

Number

1, 2, 3, or 4 - number of letters or numbers per element if applicable

Number

. 13, . 15, . 18 - size of elements if applicable

POINTER, SYMBOL, COLORS - self-explanatory

example

N-1-. 18 is a single number per element with a . 18 inch height.

TABLE I. Variable with associated number.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	M(mean)	.295	.331	.335	.339	.346	.359	.374	.388	.396	.399	.402	.407	.413	.416
control	M-ART	.248	.284	.288	.292	.3	.312	.327	.341	.349	.352	.356	.36	.366	.369
group	M-ASRT	.092	.128	.132	.136	.144	.156	.171	.185	.193	.196	.2	.205	.21	.213
	M-ASRT+ART	.139	.175	.179	.183	.190	.203	.218	.232	.24	.243	.246	.251	.257	.26
N-1-.18	M-ASRT	0	.036	.04	.044	.052	.064	.079	.093	.101	.104	.108	.112	.118	.121
	M-ASRT+ART	.047	.083	.087	.091	.098	.111	.125	.14	.148	.151	.154	.159	.165	.167
ASRT	M-ASRT	-.081	-.045	-.041	-.036	-.029	-.016	-.002	.013	.021	.024	.027	.032	.038	.04
	M-ASRT+ART	-.034	.002	.006	.01	.018	.03	.045	.059	.067	.07	.074	.078	.084	.087
	Standard Deviation	.052	.065	.069	.059	.068	.075	.071	.074	.647	.111	.09	.076	.085	.107

Table II. Summary of Results

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
.434	.454	.46	.466	.473	.497	.513	.522	.534	.541	.547	.551	.552	.564	1.028	1.053	1.052	1.11	1.114	1.145
.387	.407	.414	.419	.426	.451	.466	.475	.487	.495	.501	.504	.506	.518	.981	1.007	1.006	1.064	1.067	1.098
.231	.252	.258	.263	.27	.295	.31	.319	.332	.339	.345	.348	.35	.362	.825	.851	.85	.908	.911	.942
.278	.298	.305	.31	.317	.341	.357	.366	.379	.385	.391	.395	.396	.408	.872	.897	.896	.955	.958	.989
.139	.159	.166	.171	.178	.202	.218	.227	.24	.247	.253	.256	.258	.27	.733	.759	.758	.816	.819	.85
.186	.206	.212	.218	.225	.249	.265	.274	.286	.293	.299	.303	.304	.316	.78	.805	.804	.862	.866	.897
.059	.079	.085	.09	.098	.122	.137	.147	.159	.166	.172	.175	.177	.189	.653	.678	.677	.735	.739	.77
.105	.125	.132	.137	.144	.168	.184	.193	.206	.213	.218	.222	.224	.236	.699	.725	.724	.782	.785	.816
.105	.094	.082	.08	.107	.088	.124	.138	.106	.092	.107	.113	.125	.133	.285	.29	.332	.295	.253	.299

Table II. Summary of Results (continued)

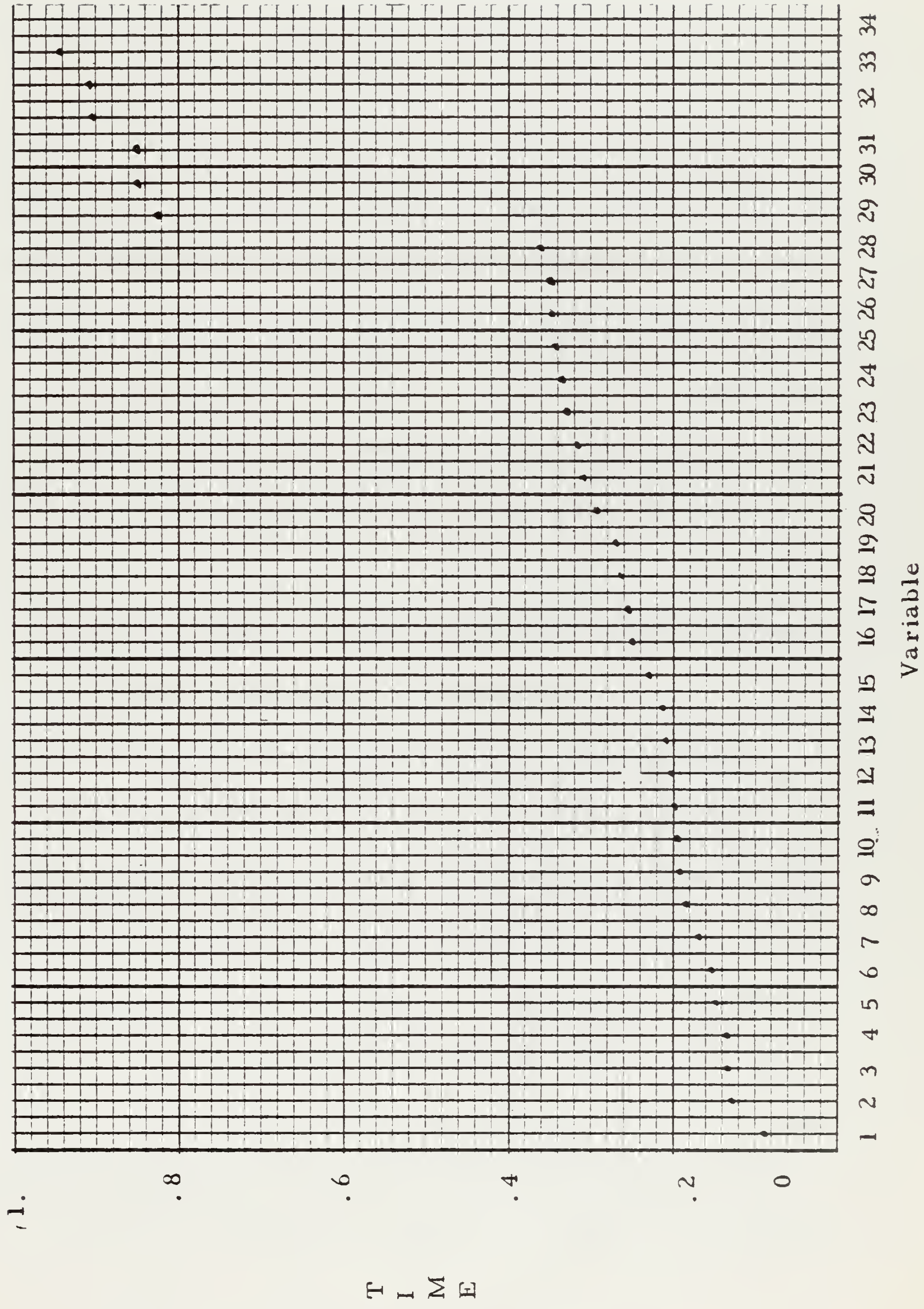


Figure 12. M-ASRT of Control Group

IV. DISCUSSION

In analyzing the data an error in the design of the eye scan slide was discovered. The eye scan was designed to be faster than any of the slides with data; however, as indicated in the ASRT Group results in Table II, there were seven slides with faster times. This probably was due to the large empty boxes with nothing in the middle to focus upon. The data was then tabulated replacing the eye scan slide with the fastest slide which was N-1-.18. This is the N-1-.18 group data. Assuming that the N-1-.18 was close but not totally accurate since the N-1-.18 slide required encoding of the numbers, a control group was used to collect eye scan data using the N-1-.18 slide in backwards so they did not have to encode the numbers. The difference per variable between N-1-.18 and the Control Group is only .092 second.

The results by time for the variables follow a logical sequence. The first six fastest of the variables are single numbers and single letters. Single numbers were the fastest and are in sequence by size, with the largest being the fastest. Single letters are a little slower and also follow in sequence by size. Numbers being faster than letters could be explained by the subject having to decide which number was presented out of a total of ten possibilities while with letters there are 26 possibilities. Meaningful words were faster than random letters (non-meaningful) due to chunking and familiarization of the meaningful

words which follow the single numbers and letters. They are also in sequence by size except for W-2-.18 which follows W-2-.15; however, the difference is only .006 second. The two-digit numbers follow the words, possibly because two-digit numbers when encoded or subvocalized are two words vice one word, i.e., 23 is twenty-three. Similarly, four-digit numbers are the longest time due to the total amount of words involved.

Colors, pointers, and symbols were hard to predict as to where they would fit in. An explanation as to why pointers took longer to encode than colors is the subject had to figure out the orientation of the pointer in addition to perceiving that it was a pointer, whereas colors were a single concept. Symbols took longer than both colors and pointers because the symbols stand for something else and must be translated to that meaning.

This logical order supports the subject's understanding the instructions to "know the meaning." The original instructions were to instruct the subjects to consciously subvocalize each variable however it was realized that subjects could possibly possess different degrees of efficiency in verbalization and also a conscious effort to subvocalize would not be the natural way of encoding data by a complex systems operator. Even though subjects were not instructed to subvocalize, when asked afterwards, 15 subjects reported that they definitely subvocalized, 4 subjects subvocalized sometimes or made an effort not to,

and 1 subject said he did not subvocalize. The order of the variables tends to support the subvocalization.

V. CONCLUSIONS

If this experiment is replicated, it is recommended that a single dot be used for the eyescan slide. Also, a red light vice a green light should be used above the rear projection screen to warn subjects not to push the button.

Other studies that could be done are: run the same experiment instructing subjects to subvocalize; use other combinations of display media such as white letters on a dark background; add abbreviations to the list of variables; use more or different sizes; incorporate stress, motivation, or varying light conditions.

APPENDIX A

TAPED INSTRUCTIONS TO SUBJECTS

The purpose of this experiment is to determine the encoding time for various symbols, letters, words, numbers, colors, and pointers. Please wait until the conclusion of the instructions for any questions you may have.

You will be required to view 40 slides as fast as you can, at the same time making sure you know the meaning of each element on the slide. You will not be required to remember any of the elements on the slides, or be tested afterwards.

First, I will explain how to view the slides, then the slides themselves.

To view the first slide, you should press the button and hold it until you are finished at which time you should immediately release the button. For subsequent slides, you are to wait for the green light above the screen to go off before you push the button. This is to give the machine enough time to select the next slide. As soon as the green light goes off, you may push the button, holding on to the button until you are finished with the slide, then releasing it just as you did for the first slide.

Now I will explain the different types of slides and how you should interpret the meaning of each one. You should follow along with me

using the examples provided.

There are two types of formats for the slides. If you look at the first example, you will notice that the first type consists of a single X covering the whole slide. When you press the button and see this slide you should immediately release the button, then wait for the green light to go off before continuing.

Please look at example 2 as this is an example of the format for the remainder of the slides. As you can see this format consists of 16 elements arranged in 4 rows and 4 columns all equally spaced. In viewing this type of slide you should scan the slide the way you read, looking at each element to make sure you know its meaning which I will explain shortly. By "viewing the way you read," I mean you should start with the far left element in the top row and when you know the meaning of that element proceed to the next element to the right. When you finish the top right element of the top row go to the far left element in the next row down and proceed to the right as you did on the first row. Continue in this manner until you are finished with all the elements on the slide, at which time you should release the button.

Now to explain the different types of elements that will be presented and what each should mean to you.

In example 2, the elements consist of random letters. This particular example consists of 4 random letters per element. In the slides of this type that you will be viewing each element may consist

of 1, 2, or 4 random letters but the number of letters per element will be the same throughout the whole slide. As you see in the four letter example there is no meaning for the total element and so you should make sure that you recognize each letter of the element be it 1, 2, or 4 letters. For this particular example the meaning of the first element is A W M W. The meaning of the second element is E C J T, then C X E G, G A J X, X V N K, and so on until you come to the last element W V O Y at which time you should release the button.

For the next type of element see example 3. These elements consist of 1, 2, or 4 numbers. For each element you should make sure you know the meaning of the number. For this example the first element is ninety-seven, the next element forty-five, etc., not nine seven or four five. A four digit number, such as 3285, would mean three thousand two-hundred and eighty-five.

Looking at example 4 you will observe the elements consist of colors. You should make sure that you know the color of each element. In this particular example the first row is green, red, blue, green.

As you will notice in example 5, the next type of elements consist of four different symbols: the triangle, diamond, circle, and square. As soon as you know the meaning of the element as being that of a triangle, diamond, circle, or square proceed to the next element.

If you look at example 6, you should recognize each of the four letter words. For other slides of this type the words could consist of

2 or 3 letters instead of 4 letters as in this example. You should make sure you know the normal meaning of the words; as in this example, C U R E is cure; R U D E is rude, and so on.

The elements of example 7 consist of pointers in four directions. By knowing the meaning of each pointer you should know the direction in which each element is pointing: left, right, up or down, as in the first row of this example: down, up, right, up.

The last type of elements are shown in example 8. Each element is an open box. When the slide is presented all you are required to do is to look at the center of each box scanning the same way, left to right, top to bottom. You should go as fast as you can, but making sure you look at the center of each box.

Now that I have explained each type of slide and the elements of each you will be given a series of 8 practice slides in which to familiarize you with the equipment and the correct responses to the different slides. After each slide you will be given the correct response. Before we start the eight slides are there any questions?

APPENDIX B

POST EXPERIMENT QUESTIONNAIRE

Name ____

Rank ____

Age ____

Designator ____

Most recent type A/C ____

Total hours ____

Post Experiment Comments:

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